Fuel Moisture Sampling in Boreal Forest Duff

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Introduction
Fire is the dominant disturbance factor in the boreal forest ecosystem of Interior Alaska. Fire and resource mangers rely on widely spaced weather stations for spatial and temporal estimates of fire danger. The Canadian Forest Fire Danger Rating System (CFFDRS) has been adopted by most of the fire management agencies through out the state and has the potential to be a very powerful tool for fire and resource managers. The CFFDRS incorporates weather, fuel moisture, fuel type and fire behavior into one complete system. The ultimate goal of the system is to produce a fire danger rating system such that any given index value will always represent the same fire behavior regardless of the preceding weather history (Van Wagner 1970). Unfortunately, very little ground truthing of CFFDRS has been done in Interior Alaska which has resulted in inconsistent use of the system within and among agencies.

Wildfire continues to be a threat to resources and urban-interface situations. Lightning ignitions and mop-up concerns are dependent on the amount of fuel available for combustion. In addition, fire personnel are also often requested to plan and implement prescribed fires or fire use fires with specific resource objectives expected to result. In boreal forest ecosystems success is often tied to fire severity which is directly related to depth of consumption of the forest floor. Therefore, the burn boss and/or the fire management personnel must have a reliable method, such as the CFFDRS Fire Weather Index (FWI), for predicting depth of organic fuel consumption. While several factors can contribute to the depth of organic material consumption, moisture content is the most easily tracked and is considered a prominent factor contributing to combustibility. The CFFDRS's FWI is basically a bookkeeping system of moisture entering and exiting various fuel layers in the forest floor.

The sampling methods in this pamphlet are designed for repeated on-site validation/calibration of the CFFDRS FWI. Destructive sampling techniques to determine actual moisture content of the organic mat are reviewed as well as time domain reflectometry (TDR) probe sampling procedures. Equations for determining moisture content from either destructive sampling or probe sampling are included as well as suggestions for data analysis and comparison of actual moisture content with FWI predicted moisture content. The sampling methods are designed specifically for the CFFDRS C-2 fuel model as this is generally considered the 'problem fuel' in Interior Alaska. ***Use of this protocol in other fuel models may require slight modifications.***

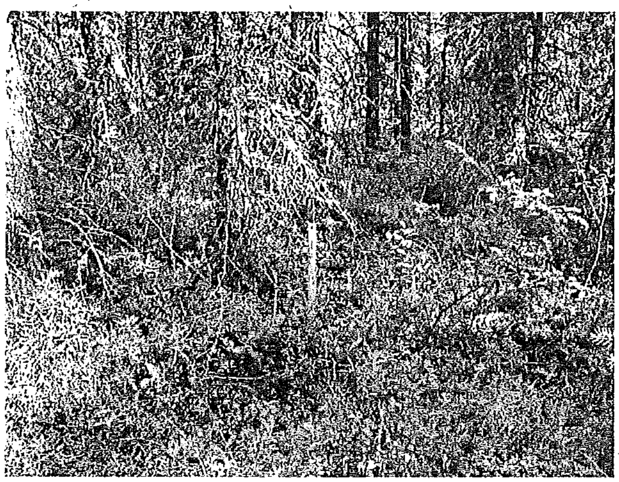

Figure 1

Site Description
C-2 sites are described as upland or lowland spruce sites with an understory consisting of Labrador Tea (*Ledum*) and feathermoss (*Hylocomium* and/or *Pleurozium*). See Figure 1. A validation or calibration project should be in close proximity to a weather station capable of collecting the appropriate FWI weather parameters. Within your site, select an area representative of the fuel model desired to accomplish the sampling objectives. A permanent plot center should be randomly selected and marked.

Destructive Sampling Techniques

Each sampling day a random azimuth will be selected as the sampling transect. A 15 meter transect will be extended from the plot center along the random azimuth and three plugs will be dug at 5, 10, and 15 meters. A center plug will be taken along the azimuth line and two additional plugs will be dug on either side of the azimuth line at least one meter from the center plug. See Figure 2. Avoid areas directly under canopy cover, areas that are not feathermoss, areas that are obvious trails, etc.. Because the moisture regime in the boreal forest is highly variable, the mean of the moisture contents from the nine plugs is used in an attempt to capture the overall moisture content of the site.

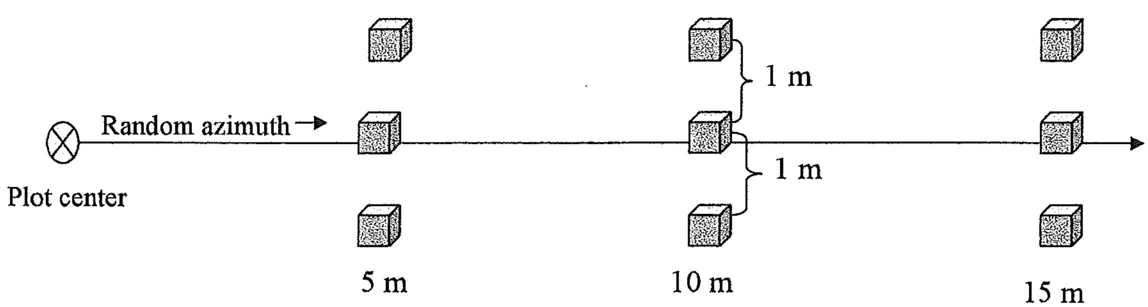

Figure 2

To extract the plug with minimal compaction, carefully saw the outer perimeter (about a six inch square) with a long serrated edge (a 12" or 14" keyhole saw is good). Reach down on two sides of the plug and remove it from the hole. Try to extract the sample all the way down to mineral soil. A long bladed tree planting spade may also be used to 'pop' the plug out if compaction can be avoided in the process.

Figure 3

Sectioning the Plug
Turn the extracted plug on its side and mark 5 cm increments from the surface down. Flat toothpicks are good markers. Clip or slice the plug at the 5 cm sections as marked. Now carefully clip each 5 cm layer into a four inch square using the grid board and plastic square as guides. See Figures 3 and 4. Try to avoid compressing the layer as you clip the square.

Remember to be precise if an accurate volumetric sample is required (volumetric samples are required when calibrating TDR type probes).

If using the grid board and the 4 inch quilting square described in the equipment list your final sample should be 516 cubic cm's (10.16 cm x 10.16 cm x 5 cm).

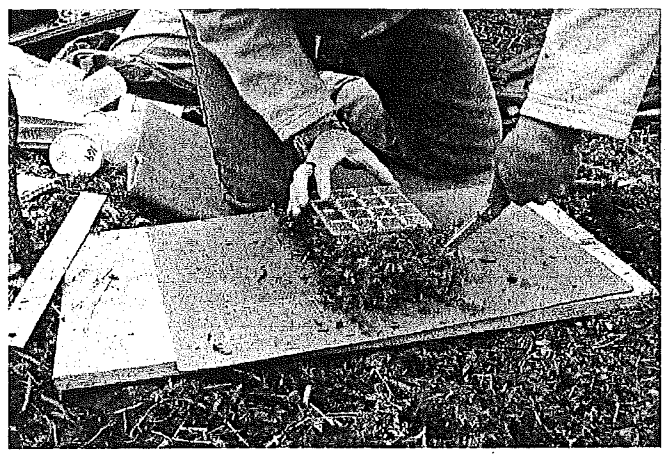

Figure 4

Now, examine the sample to determine if the fuel layers are homogenous. If two or more fuel types are represented in a single 5 cm layer the average depth of each fuel type should be recorded and the sample should be further dissected and placed in separate drying bottles. For example, the 0-5 cm layer will usually be composed of live and dead moss (and maybe even some upper duff). Be sure to document the depth and fuel type in each container.

The main transitions to look for include: live moss to dead moss, dead moss to upper duff, upper duff to lower duff, and lower duff to mineral soil. See Figures 5a - e. Live moss is considered to be the green portion of the moss, usually about 2 cm deep. The live moss layer is generally modeled by the FFMC. Dead moss is moss which is not green but has not decomposed. The dead moss is best represented by the DMC. Upper duff is material which has begun decomposing and is mostly comprised of fine stems. Upper duff may be best modeled by the BUI but, should also be correlated with DMC and DC to determine the best fit. Lower duff is fully decomposed material. It should be a much darker color and more soil like than the upper duff. Lower duff is best represented by the DC. For additional information regarding the definition of the fuel layers reference Norum and Miller (1984).

Figure 5b. Live Moss

Figure 5c. Dead Moss

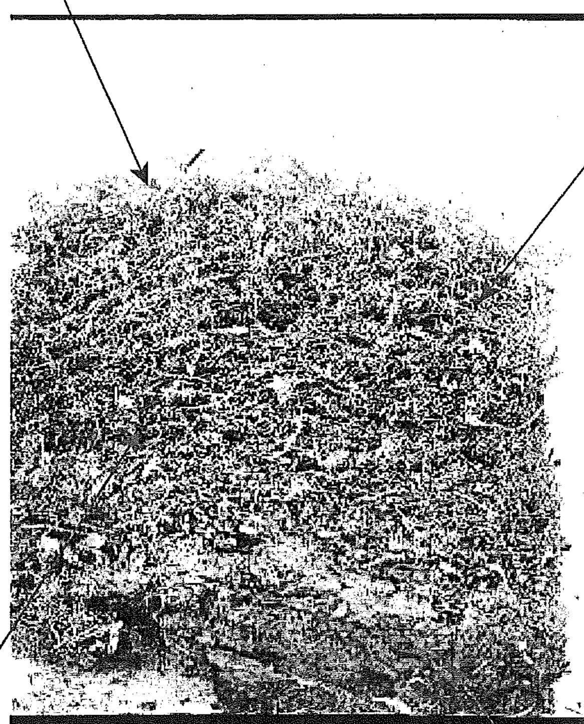

Figure 5a. Entire organic plug.

Figure 5d. Upper duff

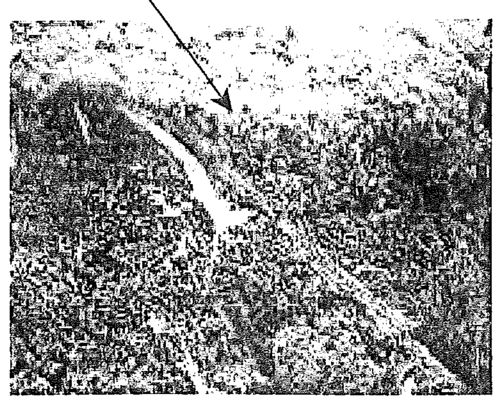

Figure 5e. Lower Duff

The purpose of sectioning the plug into 5 cm layers and then by fuel type is two-fold. The research of Busby (1978) and Sharratt (1997) has shown that the four fuel types described here have distinctly different moisture dynamics (i.e. the fuel types have different capacities for transporting and storing water). Furthermore, dissecting the 5 cm layers into fuel types produces less error in measurement for volumetric samples by fuel type.

Drying the Samples and Calculating Moisture Content
Place the samples in airtight labeled containers. Autoclavable nalgene® straight wide mouth bottles work well. Be sure bottles and lids are labeled. Record the container number and the fuel type and depth on the data sheet. The wet weight of the filled container can be determined in the field or back at the lab. After weighing, the opened containers should be placed in the drying oven and dried to a constant weight. This process is usually complete in approximately 24 hours in a 100°C oven. When the samples have reached a constant weight remove them from the oven, replace the proper lid on the proper bottle and weigh again to obtain a dry weight.

Basic fuel sampling procedures and gravimetric (dry weight based) moisture content calculations are discussed in detail in Norum and Miller (1984) and Lawson and Dalrymple (1996). Bulk density and volumetric moisture content measurements are easily determined in a similar manner. See equations 1 - 3.

Equation 1.
Gravimetric moisture content = ω

$$= \frac{(\text{wet weight of sample - dry weight of sample})}{(\text{dry weight of sample - bottle weight})} \times 100 = \text{moisture content in percent}$$

Equation 2.
Bulk density = ρ_b

$$= \frac{(\text{dry weight of sample - bottle weight})}{\text{total volume of sample}} = \text{grams/cubic centimeter } (g/cm^3) \text{ or } (Mg/m^3)$$

Equation 3.
Volumetric moisture content = θ

$$= \frac{(\text{wet weight of sample - dry weight of sample})}{\text{total volume of sample}} \times 100 = \text{moisture content in percent}$$

Recording and Analyzing Destructive Sampling Data
Figure 6 is an example of a field data sheet that includes all of the information required for complete data analysis. I would suggest using this or a similar form for recording data in the field (a blank template is included as Appendix A). Be sure to document the depth of the fuel class changes and indicate whether the sample was a volumetric sample or a gravimetric sample.

Sample #	Section	Fuel	Depth	V/G	Bottle #	Wet	Dry	Probe Depth	Voltage	Voltage	Voltage
1	1	lm	2	v	130	62.2	55.7	**0 - 5 cm**	0.056	0.056	0.063
1	1	dm	3	v	60	75.3	57.8				
1	2	dm	2	v	165	68.8	56.3	**5 - 10 cm**	0.091	0.073	0.068
1	2	ud	3	v	24	82.4	59.4				
1	3	ud	5	v	158	112.4	67.8	**10 -15 cm**	0.095	0.111	0.177
1	4	ud	5	v	9	158.6	78.3				
1	5	ld	2	g	199	181.1	88.3	**15 - 20 cm**	0.356	0.305	0.431

Figure 6

Input the data into a spreadsheet with a format similar to Figure 6. Add one additional column before the sample # column for the sampling date and call this the 'raw data' sheet. Filtering techniques or pivot tables can be developed from the 'raw data' sheet to analyze the fuel moisture either gravimetrically or volumetrically by depth or fuel type. An example of a volumetric pivot table is shown in Figure 7.

Fuel type	(All)
Section	(All)

		Sample #									
date	Data	1	2	3	4	5	6	7	8	9	Grand Total
10-May	Sum of wet wt	458	375.9	0	440.1	391.8	500.3	439.7	0	0	2605.9
	Sum of dry wt	300	265.3	0	261.3	246.9	365.1	255.5	0	0	1694.4
	Sum of tare wt	266	214.9	0	212.5	213.8	267.3	214	0	0	1388.5
	Sum of samdepth	15	15	0	15	15	20	15	0	0	95
	Volumetric MC	**10.19%**	**7.14%**	**#DIV/0!**	**11.55%**	**9.36%**	**6.55%**	**11.90%**	**#DIV/0!**	**#DIV/0!**	**9.30%**
	Bulk Density	**0.022**	**0.033**	**#DIV/0!**	**0.032**	**0.021**	**0.047**	**0.027**	**#DIV/0!**	**#DIV/0!**	**0.031**
19-May	Sum of wet wt	402.1	493	251	218.4	490.8	416	400.3	473.3	329.4	3474.3
	Sum of dry wt	321.5	318.1	180.2	192.4	346.1	324.1	265.2	361.3	269.6	2578.5
	Sum of tare wt	267.9	265.3	159	161.9	266.3	265.7	215	318.7	213.4	2133.2
	Sum of samdepth	20	20	10	10	20	15	15	20	15	145
	Volumetric MC	**3.90%**	**8.47%**	**6.86%**	**2.52%**	**7.01%**	**5.94%**	**8.73%**	**5.43%**	**3.86%**	**5.99%**
	Bulk Density	**0.026**	**0.026**	**0.021**	**0.030**	**0.039**	**0.038**	**0.032**	**0.021**	**0.036**	**0.030**
30-May	Sum of wet wt	464.2	165.7	574.8	717.7	696.2	707.1	488	364.3	364.9	4542.9
	Sum of dry wt	333.3	125.6	354.1	447.6	398.5	457.7	313.3	254	302.6	2986.7
	Sum of tare wt	267.8	106.4	267.8	374.7	322.2	371.8	265.6	213.7	264.4	2454.4
	Sum of samdepth	20	5	20	22	23	20	17	15	15	157
	Volumetric MC	**6.34%**	**7.77%**	**10.69%**	**11.89%**	**12.54%**	**12.08%**	**9.96%**	**7.12%**	**4.02%**	**9.60%**
	Bulk Density	**0.032**	**0.037**	**0.042**	**0.032**	**0.032**	**0.042**	**0.027**	**0.026**	**0.025**	**0.033**

Figure 7

The blue shaded boxes are the page, row and column entries in the pivot-table set-up. The purple shaded boxes are the data entries which are placed in the body of the table. The green shaded boxes are additional entries that require manipulating the purple shaded categories into the formulas taken from Equations 1 - 3 on the previous page. The column labeled 'Grand Total' calculates the mean moisture content or bulk density for the nine samples. The different fuel types and sections can be viewed by selecting 'fuel type' or 'section'. Statistical procedures other than the nine sample mean will require copying the data onto an additional spreadsheet.

Sampling Procedures for TDR or FDR Probes

Time domain reflectometry (TDR) and frequency domain reflectometry (FDR) probes are being found to be useful for monitoring ***volumetric moisture content*** in organic duff layers. Follow the calibration procedure outlined in the owners manual in Appendix B to fine tune the probe to the organic material of interest. The Delta-T probes available to AFS from UAF have been calibrated for feathermoss duff as follows:

Equation 4.

$$\text{Volumetric MC} = \theta = \frac{\left[(1.07 + 6.4V - 6.4V^2 + 4.7V^3) - a_o\right]}{a_1} \times 100$$

$\mathbf{a_o} = 1.099$
$\mathbf{a_1} = 8.03$

V = voltage reading from the probe

The a_o and a_1 values above were determined for dead moss and upper duff in the C-2 feathermoss fuel type in the Fairbanks area (Wilmore 2000 unpublished).

The probes can be buried in-place and attached to a continuous data logger or used as a portable unit with a hand held meter. ***Be sure to record the voltage not the moisture content*** as the feathermoss duff common in the boreal forest requires a new calibration or the custom equation given above. Follow the basic site selection and sampling transect procedures described in the destructive sampling section for collecting data.

Figure 8

The handheld Delta-T probe provides fairly accurate moisture contents for the 0-5 cm layer if it is gently inserted into the moss in a vertical position. See Figure 8. Only insert the probe far enough that the top of the live moss just touches the base of the probe. (Pressing too hard compresses the moss and gives inaccurate information.) Several reading can be quickly taken along the transect line and in the vicinity of the destructive plugs.

To determine the moisture content of layers deeper than 5 cm requires digging a hole that will enable the probe to be inserted horizontally at multiple depths. See figure 9. Again, try not to compress the material being probed.

To test the accuracy of the probe a destructively sampled plug should be probed in each of the fuel types or by the 5 cm depth classes. The volumetric samples from the plug can be compared to the probe reading to determine accuracy. The data sheet in Figure 6 and Appendix A includes a column for recording probe voltage readings. If the probe proves to provide an acceptable estimate of moisture content the number of destructive samples can be reduced.

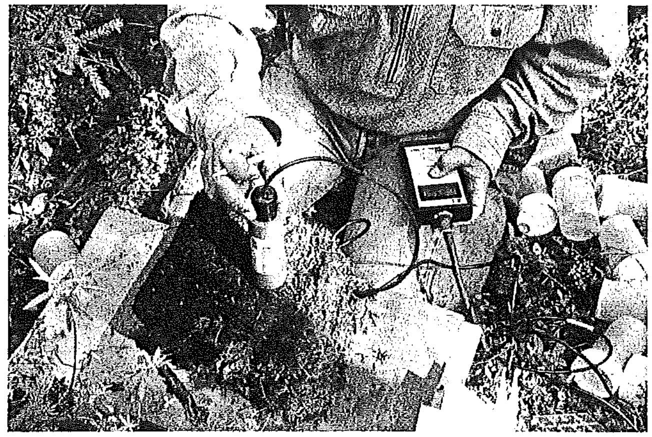

Figure 9

Because fire danger rating systems use dry weight based moisture contents any volumetric measurements will have to be converted to gravimetric measurements. This is easily achieved if one knows the bulk density of the fuel using equation 5a and 5b taken from Hillel (1998).

Equation 5a.
Volumetric Moisture Content = gravimetric moisture content X bulk density
or $\theta = \omega\ \rho_b/\rho_w$

Equation 5b.
Gravimetric Moisture Content = volumetric moisture content / bulk density
or $\omega = \theta\ \rho_w/\rho_b$

Gravimetric moisture content = ω
Volumetric moisture content = θ
Bulk density = ρ_b
Bulk density of water (1 g/cm^3) = ρ_w

Average bulk densities for feathermoss fuels in the Fairbanks area are as follows (Wilmore 2000 unpublished):

Live moss = .014 g/cm^3 1.59 t/a/in
Dead moss = .023 g/cm^3 2.61 "
Upper duff = .045 g/cm^3 5.16 "
Lower duff = .110 g/cm^3 12.46 "

These bulk densities are also consistent with previous research in the feathermoss duff layer (Barney et al. 1981).

Recording and Analyzing Probe Sampling Data
To determine the volumetric moisture content of the site compute the mean of all of the voltage readings taken at similar depths or in similar fuel types. Use Equation 4 to determine the volumetric moisture content from the mean voltage. Compare this volumetric moisture content to the destructively sampled volumetric moisture content to check the accuracy of the probe calibration. The gravimetric moisture content can be determined using Equation 5b. The bulk

densities used in the equation can come from the bulk density data in the pivot table or from the averages given on the previous page.

Comparing Actual Moisture Contents to CFFDRS Indicies and Predicted Moisture Contents

Weather and FWI data can be found and downloaded from the AFS Home Page. Lawson and Dalrymple (1996a) and Lawson, Dalrymple and Hawkes (1997) explain the correlation of fuel moisture to fuel codes. These publications are available in the AFS reading file located in the Fuels and Fire Ecology office. The EXCEL spreadsheets are the basic start for any further statistical analysis - ***Be Creative***.

Required Equipment

long bladed soil shovel
12" blade keyhole saw
sharp clippers
serrated edge pocket knife
4" quilters square
1" gridded mat (at least 12" x 16")
flat wooden toothpicks
plot center marker
15 m tape

References

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Sharratt, B.S. 1997. Thermal conductivity and water retention of a black spruce forest floor. Soil Science Vol. 162: 576-582.

Barney, R.J.; C.D. Bevins, and L.S. Bradshaw. 1981. Forest floor fuel loads, depths, and bulk densities in four interior Alaskan cover types. USDA Forest Service Intermountain Forest and Range Experiment Station, Research Note INT-304. pp.1-7.

Appendix A

date	Sample #	Section	Fuel type	sam depth	V/G	tare#	wet wt	dry wt	tare wt	Probe depth	Voltage	Voltage	Voltage

Appendix B

Soil-specific Calibration

1. Collect one or more plugs of organic material using the destructive sampling procedures described in the protocol above. Bring the entire plug into the lab and let any excess water drain for several hours.

2. Cut the plug into known volume samples and record the depth and/or fuel type as described in the protocol.

3. Probe the volumetric sample in several places recording the voltage output on the handheld meter. Use the average voltage reading for each depth or fuel type in the calibration equation.

4. Dry the samples to a constant weight at 100°C. Probe each dry sample in several places and use the average voltage reading by depth or fuel type in the calibration equation. *The dry probe readings should be fairly consistent.*

5. Insert the average wet and dry probe readings into the polynomial equations in the ThetaProbe User Manual pages 10-12.

The $\mathbf{a_0}$ and $\mathbf{a_1}$ constants of $\mathbf{a_0} = 1.099$ and $\mathbf{a_1} = 8.03$ that I arrived at are giving good estimates of volumetric moisture content when compared to destructive volumetric samples of known depth or fuel type.